

# Development of Fracture Splitting Method for Case Hardened Connecting Rods

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## Abstract

The fracture splitting (hereafter FS) method is being increasingly used for manufacturing connecting rods that are made of the powder forging material, high-carbon steel, etc., which are comparatively easy to fracture, in order to improve the accuracy and productivity. On the other hand, case hardened steel (for instance, JIS SCM420), which has a high fatigue strength, is used for the connecting rod in high performance motorcycles in order to reduce the motorcycle's weight.

In this report, the application of the FS method was examined for manufacturing the connecting rod which used the JIS SCM420 carburized steel. The hardness of this material varies according to the depth from the surface, becoming less hard and less brittle toward the center. Therefore, a brittle fracture surface over the entire fractured surface area was not obtained by the conventional fracturing method, and it was impossible to reassemble the fractured parts. Moreover, there was a problem that the fracture starting point was irregular and it caused the breakaway of tiny fractions from the fracture surface. The condition to obtain the brittle fracture surface was then elucidated using a weight falling-type splitting machine with the temperature and the virtual strain rate as parameters. Moreover, as for the fracture starting point, measures were taken by analyzing it using the nonlinear simulation of the explicit method. The production of the connecting rod for the Yamaha supersport model YZF-R1 (**Figure 1**) using this method was started in 2003.



Figure 1. YZF-R1

## 1 INTRODUCTION

Generally, the connecting rod for a multiple cylinder engine has a structure such that the big end can be separated into the rod and the cap in order to assemble it with the crank shaft (**Figure 2**). Recently, in order to improve the accuracy and to



Figure 2. FS carburized connecting rod

decrease the manufacturing cost for the connecting rod having such a structure, the Fracture Splitting (FS) method has attracted attention, and its adoption is being seriously considered.

In the FS method, the cap and the rod are forged and machined in the form of one body, and then the body is separated into two pieces by making an impact, forming a notch groove at the inside diameter of the big end as the crack initiation point. As a result, the machining for positioning becomes unnecessary because precise positioning during assembling becomes possible by

having the fractured surface face each other. Reduction of the production cost becomes possible by applying this method due to the integration of the machining processes of the cap and the rod and the elimination of machining the end face and positioning. Moreover, the efficacy of improving the reliability and decreasing the power loss is expected because the accuracy of the inside diameter of the big end is improved due to the improvement in the positioning accuracy between the cap and the rod.

The application of the FS method for the production of the connecting rod using sintered forged steel was started in the 1990's [1]. The applications of the FS method for the connecting rod using a high fatigue strength material were then examined due to the requirement of improving the engine performance and the fuel economy. Olaniran et al.[2] and Repgen[3] developed a method for applying the FS method to forging steels, which have a higher fatigue strength compared to the sintered forged steel. Furthermore, Fukuda et al.[4], Inoue et al.[5] and Park et al.[6] developed a method for applying the FS method to microalloyed steel, which excels in fatigue strength and machinability among the forging steels. The microalloyed steel developed by Inoue et al. exhibited a fatigue limit that reached 480MPa. All these materials had improved cracking capability due to the increase in the brittleness while maintaining or improving the fatigue strengths, therefore, the application of the FS method was enabled.

On the other hand, as for the heat treatment, the quenching and the tempering is effective for obtaining forging steels with a higher fatigue strength. In particular, the carburizing quenching and tempering of the low carbon case hardening steel is widely used for the connecting rod of high performance small engines in view of the balance of

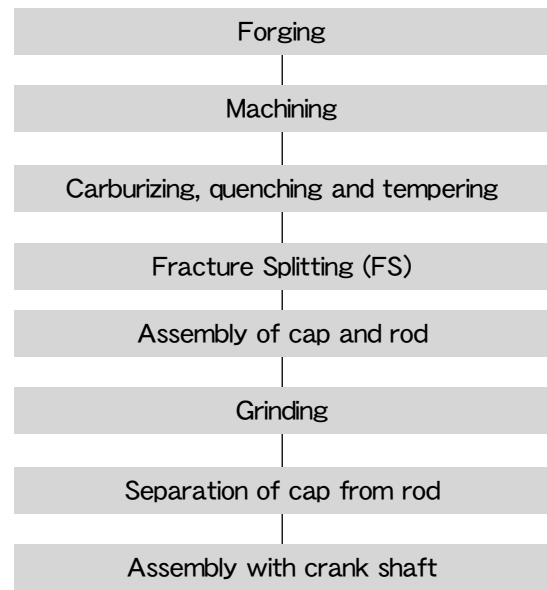


Figure 3. Fabrication process for carburized FS connecting rods

machining ease before the heat treatment and the high fatigue strength and toughness after the heat treatment.

In this report, the application of the FS method was examined for connecting rods made of carburized quenched and tempered steel of JIS SCM420 (effective hardening depth: 0.5mm, fatigue limit: 800MPa, hereafter abbreviated as SCM420 carburized steel), which is generally used for large volume displacement motorcycle engines. The properties of this material are the hardness changes in accordance with the depth, and the hardness and the brittleness are lower on the inside. Therefore, there were some problems such that a brittle fracture was not obtained for all the fracture surfaces and the mode of the fracture was irregular. Consequently, these two problems were examined.

## **2** CONDITIONS OF OBTAINING BRITTLENESS FRACTURE SURFACE

### **2.1 Target**

One of the properties required for the FS method is that the shape and the dimensions of the connecting rod after assembly do not change during processing. Moreover, it is required to have a precise positioning within microns by facing the fracture surface in order to assemble the cap and the rod. Therefore, the fracture surface is required to undergo brittle fracture, and various examinations were carried out on the characteristics of the material and the fracture conditions [2-6].

In the vicinity of the surface of the SCM420 carburized steel, it is easy to obtain a brittle fracture due to the high carbon and high hardness. However, on the inside, it is expected that the brittle fracture is not easily obtained compared to the material examined up to now because of the low carbon and low brittleness. For instance, the Charpy impact value of the JIS3 test specimen was 19-23 J/cm<sup>2</sup> for the forging steels [5], which has been evaluated for the FS method, while it is 59J/cm<sup>2</sup> or more for the inside of this material [7]. The fracture condition for obtaining the brittle fracture over the fracture surface including the inside was examined for the SCM420 carburized steel.

## 2.2 Experimental procedure

Concerning the fracture conditions, it is postulated that the condition required for the actual connecting rod cannot be reproduced by the standardized test method such as the Charpy impact test, etc. The test method similar to the production method was done using the actual connecting rod as the test piece in order to reflect the results obtained under production conditions. A schematic drawing of the test method is shown in **Figure 4**. The test piece was prepared by the following method: the JIS SCM420 material was hot forged into the shape of the connecting rod, and after the machining was completed, it was subjected to carburizing, quenching and tempering. The distribution of the hardness is shown in **Figure 5**. Grooves for the crack initiation were formed by electric discharge machining on the inner surface of the big end. The shape of the grooves is shown in **Figure 6**.

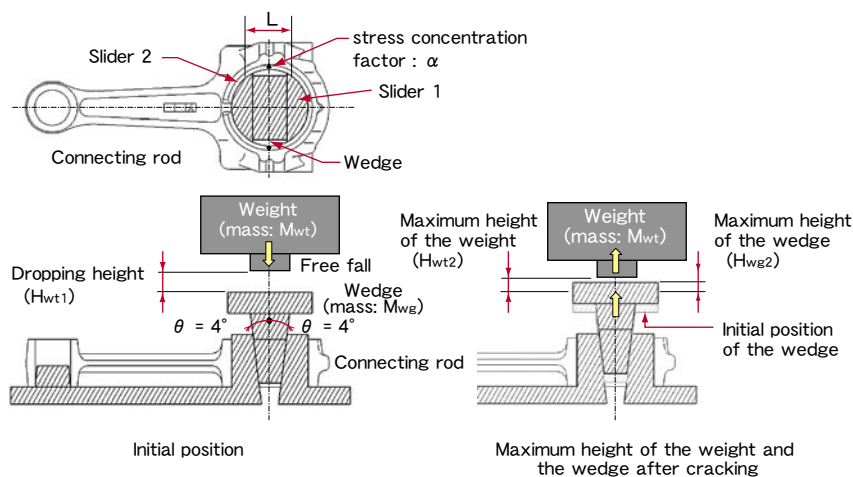


Figure 4. Connecting rod and jigs for FS experiments

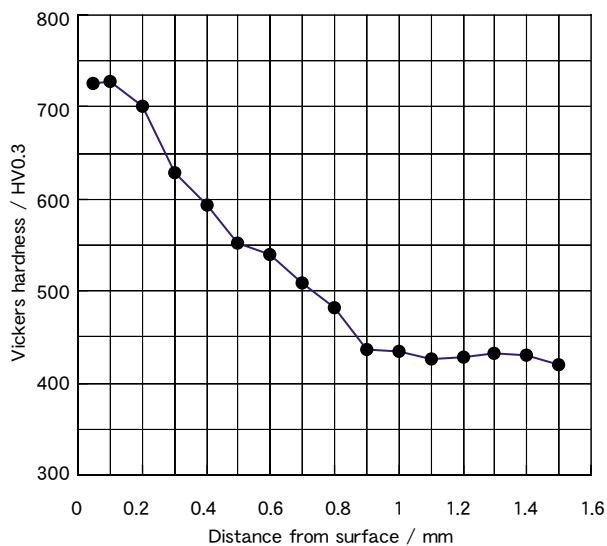


Figure 5. Hardness of specimen

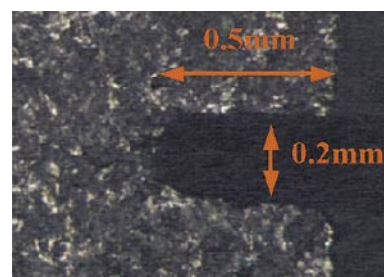


Figure 6. Shape and dimension of the groove

It is considered that a significant energy is required for fracture of the SCM420 carburized steel compared with the conventional material. In order to examine the fracture conditions of such a material, a falling weight type splitting machine was used. As shown in **Figure 4**, the potential energy of the weight is given to the wedge, and the wedge opens the slider in the direction of the axis of the connecting rod, and it breaks the big end of the connecting rod. After fracturing, the weight is repelled up with the damper. This splitting machine can produce a larger energy and larger distortion velocity compared to the splitting machine activated by an oil hydraulic press, crank press, etc. Furthermore, the rate of strain and the energy can be easily adjusted by changing the mass of the weight and its falling height.

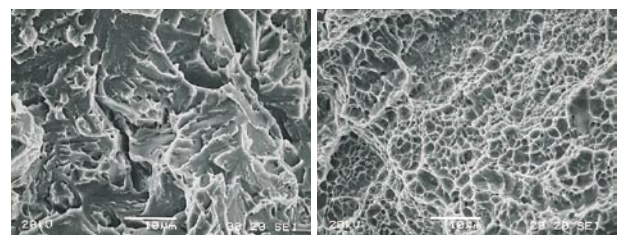
In this test method, the brittleness transition of the fracture surface cannot be measured by a method like the Charpy impact test, etc., because the energy absorption due to the friction of the jig, etc., cannot be accurately calculated. Two parameters of the "Quasi-Absorbed Energy" and the "Quasi-strain ratio" were then defined for this test method. The Quasi-Absorbed Energy is the total sum of the energy, which was absorbed by the connecting rod and the jig during fracturing, and is defined as follows:

$$E = M_{wt}gH_{wt1} - M_{wt}gH_{wt2} - M_{wg}gH_{wg2} \quad (1)$$

where  $M_{wt}$  is the mass of the weight,  $M_{wg}$  is the mass of the wedge,  $g$  is the gravitational acceleration,  $H_{wt1}$  is the initial height of the weight,  $H_{wt2}$  is the maximum height of the weight after the fracture, and  $H_{wg2}$  is the maximum height of the wedge (**Figure 4**). The height of the weight and the height of the wedge were measured by a laser displacement meter. Moreover, the Quasi-strain ratio was defined by the next equation.

$$S = \frac{2V_{wg} \tan 4^\circ}{L} \alpha \quad (2)$$

where  $V_{wg}$  is the maximum velocity of the wedge,  $\alpha$  is the stress concentration factor at the bottom of the grooves starting the fracture, and  $L$  is the distance between the working points of the slider (**Figure 4**). The fracture surface was observed by SEM (Scanning Electron Microscope) as a method for determining the brittleness/ductility of the fracture surface. The one, which exhibited a cleavage fracture surface over the entire fracture surface of the connecting rod as shown in **Figure 7a**, was defined as having a brittle fracture surface, and the one, which exhibited dimples as shown in **Figure 7b**, was defined as having a ductile fracture surface.



a. Cleavage fracture                      b. Dimple

Figure 7. Fracture Surfaces

### 2.3 Results

**Figure 8** shows the relations between the fracture temperature and the Quasi-Absorbed Energy examined at the Quasi-strain ratio of  $10 \text{ sec}^{-1}$ . The fractography varied at the temperature of 230K and the Quasi-Absorbed Energy of about 45J. The ductile-brittle transition temperature in this test method is considered to be 230K at the Quasi-strain ratio of  $10 \text{ sec}^{-1}$ . The relations between the fracture temperature and the Quasi-strain ratio are shown in **Figure 9**. Under the condition of the Quasi-strain ratio of  $7.5 \text{ sec}^{-1}$  or less (broken line), it was impossible to stably obtain a brittle fracture surface regardless of the fracture temperature. At the higher Quasi-strain ratio, changes in the fractography were observed as indicated by the alternate long and short dashed line. These two borders are the ductile-brittle transition lines, which indicates the condition in order to obtain a brittle fracture surface by this test method.

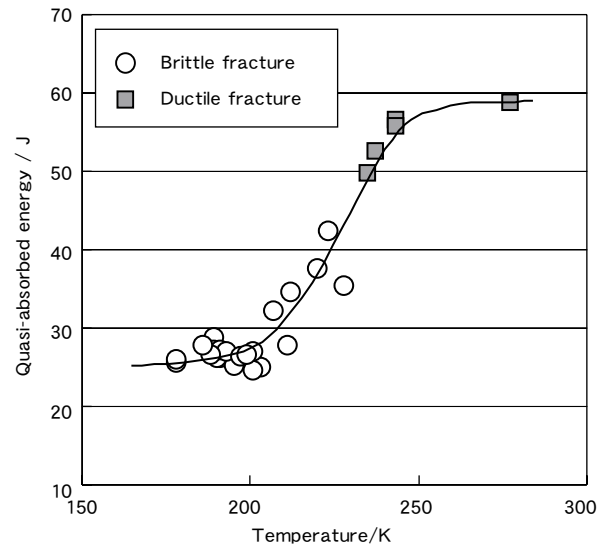


Figure 8. Relationship between temperature and Quasi-Absorbed Energy

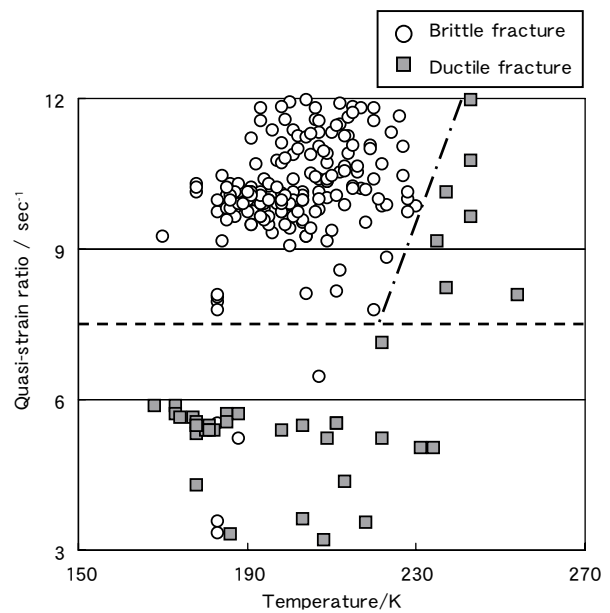


Figure 9. Relationship between temperature and Quasi-strain ratio

### 3 CAUSES AND MEASURES OF MULTIPLE FRACTURE SURFACE OCCURRENCES

#### 3.1 Target

Among the connecting rods, which had the brittle fracture surface, gaps were observed in three areas, i.e., (i), (ii), and (iii) in **Figure 10**. These gaps occurred by the overlapping of multiple fracture surfaces as shown in **Figures 11** and **12**. As for gap (iii), it was confirmed not to be a problem for manufacturing and use. However, as for gaps (i) and (ii), there is the possibility of producing a tiny fraction during the processing when the machining allowance for chamfering and grinding overlaps with the gap as shown in **Figure 12**. This tiny fraction separates from the fracture surface when the cap and rod are separated. Afterwards, it is likely to become a problem when in use as for the inclusion in engine oil or it becomes the cause of defective assembly due to sticking between the two fracture surfaces during assembly of the crank. Therefore, it is necessary to investigate the cause of these cracks and then prevent the occurrence of such gaps.

#### 3.2 Experimental procedure

In order to investigate the cause of the multiple fracture surface, a nonlinear simulation of the explicit method, which could calculate the high-speed impact phenomenon, was carried out. The stress that was generated at the cross section was analyzed, and the portion where there was the possibility of starting a fracture was investigated. LS-DYNA960 was used as the

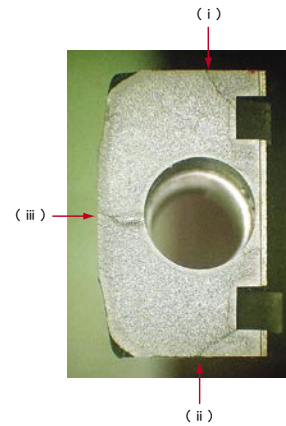


Figure 10. The gap in the fracture surface

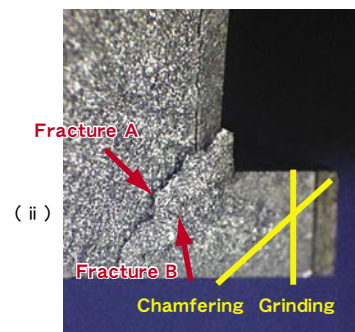


Figure 11. Enlargement of Figure.10(ii)

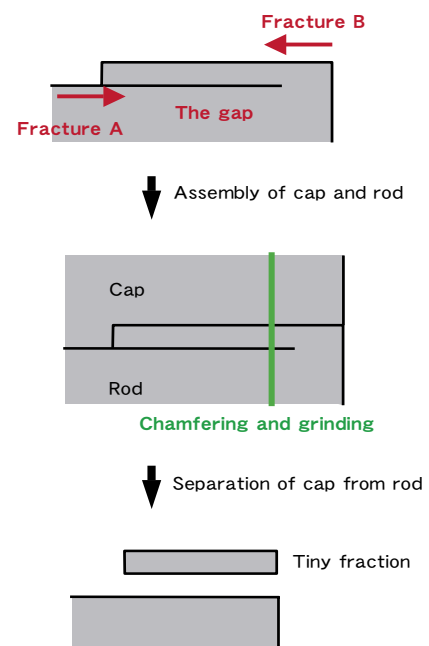


Figure 12. Schematic cross section of the gap

solver.

A half size model was selected by taking the symmetry of the entire body into consideration. The general view is shown in **Figure 13**. The point at which the weight came in contact with the wedge was defined as the starting time, and the initial velocity of the weight was assumed to be 650 mm/sec. Moreover, the calculation was carried out by assuming that the wedge and the slider were solid bodies. For the shape of the connecting rod, the calculation was carried out for the shape such that the groove of the crack initiation point at the edge was removed, besides the current shape. (**Figure 15**)

### 3.3 Results

The results of the stress analysis by the simulation are shown in **Figure 14**. The stress was concentrated at 3 points (a, b, and c) in the figure, and the possibility that these gaps independently became the crack initiation points was confirmed. It is considered that gaps (i) and (ii) occurred by joining of the fracture surfaces, which started at the stress concentration zones of points a and b, and points b and c, respectively. The crack initiation point grooves at points a and c were then removed in order to decrease the stress concentration in this area (**Figure 15**), and the simulation was carried out again. As a result, it was confirmed that the stress concentration at points a and c were relaxed as shown in **Figure 16**. The connecting rod having this shape was experimentally manufactured and

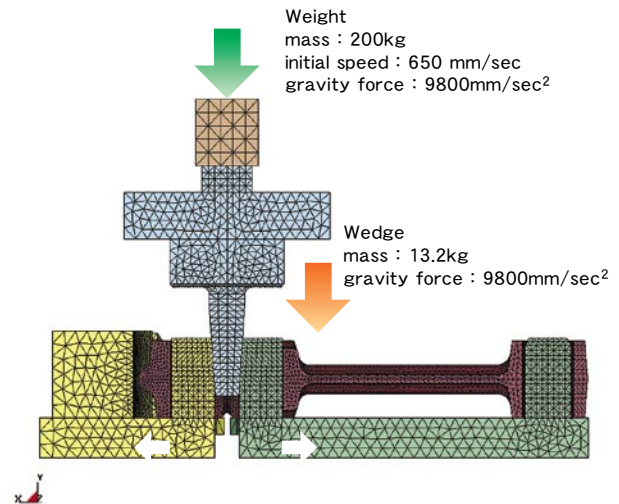


Figure 13. FEM simulation of the FS method

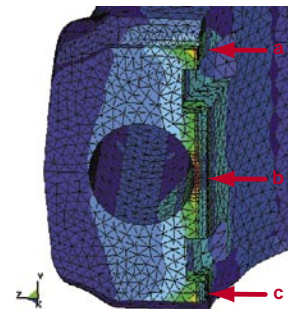


Figure 14. Stress distribution in the cross section

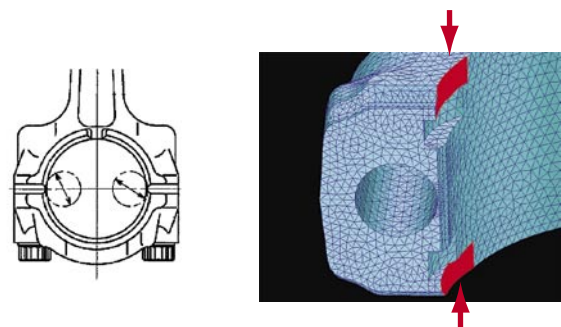


Figure 15. Machining shape of the cross section

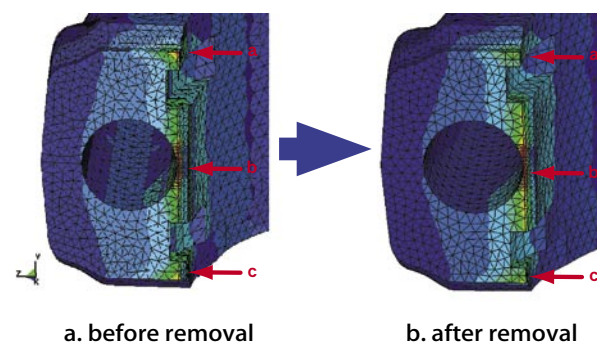


Figure 16. Stress distribution in the cross section



tested. No fracture surface that originated at points a and c was observed as shown in **Figure 17**, and it was confirmed that the occurrence of gaps (i) and (ii) could be prevented. As a result, it was confirmed that the tiny fractions did not occur during the processing after the splitting.

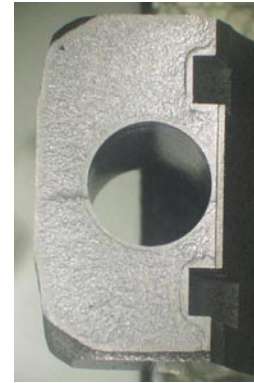


Figure 17. Fracture surface after stress reduction

#### 4

## CONCLUSION

Two problems were examined for use of the FS method for making connecting rods using SCM420 carburized steel.

1. It was found that the temperature and the Quasi-strain ratio affected the brittleness of the fracture surface, and the ductile-brittle transition line was selected as the variable in order to determine the condition for obtaining a brittle fracture surface.
2. Concerning the cause of the multiple fracture surface and the efficacy of its measures, it was found that they could be investigated by a nonlinear simulation. As a result, the occurrence of the tiny fractions during the processing after the splitting could be prevented.

Consequently, the application of the FS method for making the connecting rod, which used SCM420 carburized steel with the fatigue limit of 800Mpa, became possible, and increased the efficacy of reliability improvement by improving the accuracy of the big end part with about a 30% reduction in the production cost for small high performance motorcycle engines. The production of the connecting rod for the supersport model YZF-R1 using this method was begun in 2003.

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